PROBABLE ECONOMIC EFFECTS OF WIND POWER FOR INDIANA COUNTIES
A LITERATURE REVIEW

This section of the report reviews the academic literature on the local economic effects of wind power in order to provide insights into the likely implications for Indiana counties that allow construction and operation of utility-scale wind turbines. The capital-intensive nature of wind energy production means that the primary economic consequences of wind energy investments in a county are likely to flow from the industry's direct payments to local individuals, firms, and governments. With this in mind, we first offer a flow chart documenting the types and kinds of revenue flows that are directly related to the industry's presence in a county. The chart also highlights important "leakages," in which funds the industry invests and the revenues it earns during operations leave the county. An important source of leakage in this industry is outside investors' return on invested capital.

Next, we turn to a description of the possible economic consequences of the industry's location in a county. One should expect that the industry's presence alone will lead to modest impacts on the level and distribution of income in a county, as well as on employment. The industry's presence may also affect the structure of the local economy, through what is known as "spillovers." Because the industry makes payments to local governments – and makes some demands upon the infrastructure – one should also expect an impact on the budgets of local governments. Academic study of the impact of the industry on local public finances has centered on the industry's effects on school revenues/spending and, to a lesser degree, the effect on local tax rates. We also discuss evidence on externalities that have been linked to the industry's presence.

Most of the studies we review in this chapter use one or another form of "multiplier." A multiplier in this context relates to the scale of new wind energy capacity in a county to the scale of the change in some variable of interest. So, for example, a study focused on the effects of wind power on per capita income in a county might say that each megawatt (MW) of new generation capacity generates an additional $0.50 per year in per capita income. Using this estimate, we would infer that a county with 100MW of new capacity would have experienced a $50 per person increase in average annual income; 500 MW of new capacity would imply an increase of $250 per person.[1]

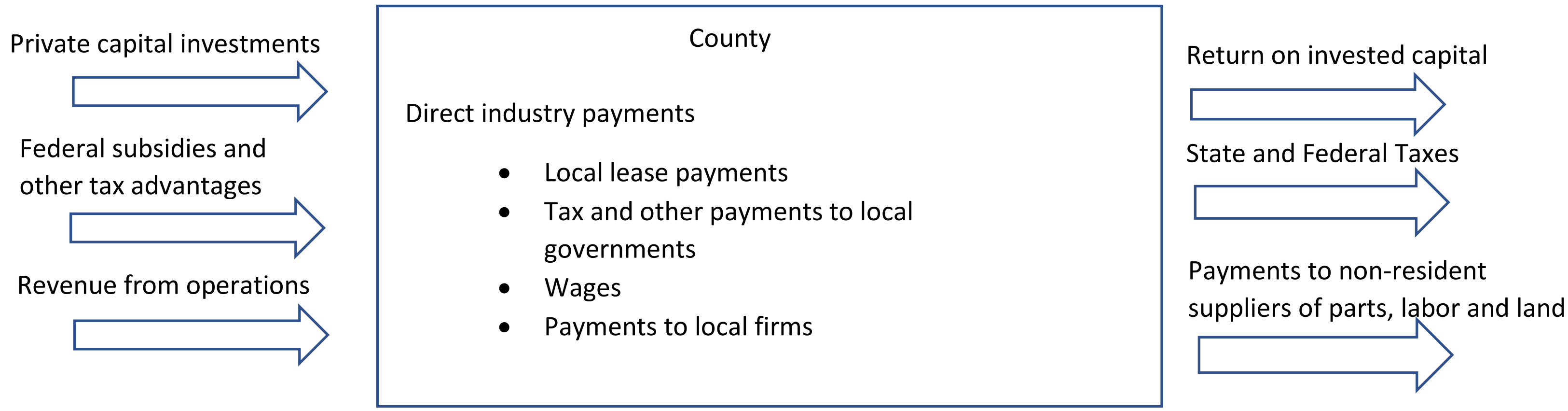
Most of the studies we review share one of two broad methodological approaches: econometric estimation or input-output modeling. Each methodology has its strengths and weaknesses, but for

[1] The studies we find to be most credible relate per capita income to *MW/capita* of installed capacity, not simply to *MW* as in the example. The use of MW/capita is appropriate in most cases, but it means that the relationship between MW and per capita income is not linear, as in the example. We use a linear example to familiarize the reader with the multiplier concept.

the purposes of this review, the econometric estimates are preferred. The circumstances of the wind-energy sector's growth – overall US wind capacity grew rapidly over a short period of time, with many counties receiving large investments while otherwise similar counties received none – are circumstances that are very well suited for credible econometric analysis. Since econometric analysis relies on historical data, these studies are becoming more common as more data becomes available.

Many other studies have used input-output models to study the economic consequences of wind power. The county-level focus of this report makes such analyses less useful than they otherwise would be. In rural areas where wind energy generation is most feasible and most common, county economies are generally quite small. The prevalence of sizable leakages from the county - leakages that are difficult to measure - makes it difficult for input-output analysis to answer these questions credibly. There are a relatively large number of input-output studies on the impact of wind energy on state economies, and we will review the first input-output study of the impact of wind energy generation on Indiana in some detail.

Figure 4. Schematic representation of revenue flows



Possible economic consequences of the wind generation industry

- Changes in the level of per capita income and employment
- Changes in the distribution of income
- Changes in local government revenues and government services
- Changes in the structure of local economies (Spillovers)
  - Effects on related industries
  - Scale effects on local business
  - Crowding out
- Externalities

I. Analytical Framework

The framework that orients our analysis is displayed in Figure 4, which offers a qualitative representation of the flows of funds that follow a county's decision to allow the construction of utility-scale wind turbines. On the left side of the figure are monetary inflows to the county. These include private investment capital in the early stages of the project, revenues from operations once the project is up and running, and a variety of subsidies and tax advantages to investors that operate at both stages of the project. In the center of the figure is a list of direct payments made to local entities. On the right side of the figure are outflows of revenues, which include returns on capital to outside investors, tax payments to higher levels of government, and industry payments to non-residents - non-resident landowners and workers, and suppliers of parts and equipment. Both the inflows and the outflows of funds are large. The primary interest of this study is the consequence of the portion of the inward flows that do not leak out of the county. At the bottom of Figure 1, we provide a list of the types of possible economic consequences of the industry's presence, and this list forms the structure of our review of the available evidence.

One of the most striking features of the wind-generated electricity industry is its high level of capital intensity. Investors - almost all of them residing outside the Indiana counties of interest - make substantial investments to install the turbines. The cost of installing each turbine can range from $2 to $4 million. Although federal subsidies and favorable tax treatment reduce the risks borne by these investors, the risks are still significant, and investors expect a reasonably high rate of return on their capital if they are to make such significant long-term investments. A high rate of return on capital applied to a capital-intensive industry means that a large share of the income generated by the turbines will inevitably be returned to outside investors. Payments to local entities constitute a smaller share of industry revenues. But the relatively large size of the industry – relative to the size of small rural economies – can mean that the industry's payments to local individuals, firms, and governments are large enough to have a quantitatively significant impact on local economic outcomes. Key questions that local governments should ask in this context are:

- How large are the local economic benefits the industry would bring?
- Are there local policies that would enlarge these benefits?
- Can the economic benefits of the industry be spread more widely across the local population?
- What negative consequences might also be attached to the industry's presence?

Before turning to estimates of the quantitative consequence of accepting the location of wind turbines, we first define the concepts that we use to consider the economic costs and benefits of accepting turbines in a county.

II. A compendium of possible economic effects of the industry on the local economy

In Figure 1, we illustrate the sources of economic impact and other possible effects of wind energy production on local economies into five categories. The first, and most important, category of economic consequences are changes in the level of income and local employment. The most significant sources of these changes are likely to be direct payments the industry makes to county residents, whether they be locally resident employees, local landowners, or other firms. Payments the industry makes to local governments might also be expected to directly support additional local employment and indirectly contribute to higher local incomes.[2]

The second category of economic impacts is the effect of the industry on the distribution of local income. Due to data availability, most economic studies limit themselves to study of the industry's effect on total economic activity or employment. But the benefits to the industry are likely to be concentrated - with affected landowners and employees receiving the bulk of the industry's direct payments. Since any disamenities that the sector might cause are shared more widely across the population, distributional effects of the industry's economic impact are salient in local political discussions of the issue. There is very little academic evidence on the consequences of the industry for the local distribution of income, but we raise it here because of its saliency.

The most plausible means for addressing distributional consequences of the industry's presence are payments by the industry to local governments. New sources of revenue for local governments can be used to offset the tax burden on other local residents and/or to provide improved public services. The section of this report that profiles the wind energy generation industry in Indiana offers anecdotal information on payments the industry has made to local governments. Econometrics or other statistical studies have investigated the effects of the industry on county tax bases, tax revenues, and school district expenditures, and we review these below.

The next category in the figure is "spillovers," that is, various ways that the industry might affect the structure of the local economy (apart from merely providing a new source of income to county residents). Spillover effects on related industries may operate through purchases of inputs from local businesses, or through the creation of new, related industries.[3] In the rather small economies

[2] Payments to local governments may include regular tax payments and/or non-tax payments such as the "economic development payments" discussed in the section of the report that profiles the wind industry in Indiana.
[3] NREL (2014) discusses the creation of a small wind tourism industry in Benton County, which is anecdotal evidence of spillover effects. They also discuss in detail how an Earl Park garage business expanded to serve the

of rural Indiana counties, additional local income generated by the industry may increase the viability, the scale, or the number of local retail establishments. On the other hand, the industry might compete with local firms for resources – bidding up wages of local workers, for example – in what is known as a "crowding out" effect. There is, as yet, relatively little econometric evidence on spillover effects, but we review one paper that investigates these effects empirically.

The final category of consequences the industry might impose is "externalities" on local businesses and on local residents. An externality is defined as a "situation when the effect of production or consumption of goods and services imposes costs or benefits on others which are not reflected in the prices charged for the goods and services being provided."[4] These would include any costs or benefits of the industry on county residents that are not compensated. The industry's most apparent externality is the change it brings to a county's visual landscape. Other externalities - less far-reaching than the visual impact - are the flicker of shadows on the nearby ground and the sounds emitted by the turbines during operation. The magnitudes of externalities are quite difficult to measure, especially when they apply to diverse populations with different aesthetic preferences. We briefly review a broader literature that attempts to quantify the effect of turbines on nearby property values. We also discuss a study showing the positive effects of turbines on crop productivity.

III. Impacts on the level of economic activity and employment

For local officials who are considering whether to allow utility-scale wind turbine investments in their county, one of the most central questions is likely to be: what will be the impact on the local economy? An analytical tool has been developed to study these impacts, a regional input-output model known as the Jobs and Economic Development Initiative (JEDI). We review the first JEDI study in Indiana. The most useful pieces of evidence on the effects of wind energy on aggregate economic outcomes come from two econometric studies.[5] We review these and calculate the implied impact on Indiana counties that comes from their results.

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industry. Our objective here is to investigate more systematic evidence that the industry affects the structure of local economies.

[4] Khemani and Shapiro (1993) cited by Organization for Economic Cooperation and Development at https://stats.oecd.org/glossary/detail.asp?ID=3215, downloaded March 16, 2020.

[5] Econometric studies are backward looking studies that employ statistical tools to compare economic outcomes in counties that where wind power investments were made to otherwise similar counties where such investments were not made.

III.a. Input-output analyses

The most comprehensive study of the industry's economic effects that focusses specifically on Indiana is a study that employs a regional input-output model to assess impacts on the state as a whole. National Renewable Energy Laboratory (NREL, 2014) uses the JEDI model to study the economic impacts of the first 1000 MW of installed capacity in Indiana. The first-1000-MW frame of the study means that it considers projects built between 2008 and 2011, which were 70- and 80-meter turbines located in Benton and White counties.[6]

The JEDI model was developed to facilitate input-output modeling of the wind sector and has been applied to the study of wind power in many different US states.[7] The primary objective of input-output models is to measure and to incorporate into the analysis, the activities of "upstream" sectors that supply the project, as well as industries even further upstream (the industries that supply the suppliers, and the industries that supply them, etc.). The analysis uses an input-output table to track each industry's purchases from each other industry. Applying a mathematical formula known as an infinite sum to the input-output table produces a multiplier that is then applied to the direct measures of investment and/or employment that are taken from project-level data. A key reason that the wind-energy sector has adopted input-output modeling as an analytical tool is that turbines themselves are extremely complicated pieces of machinery that involve long supply chains.[8] These methods are an attempt to quantify the scale of upstream sectors' participation in economic activities related to wind energy production.

As measures of changes in economic activity, input-output models have several well-known analytical weaknesses, weaknesses that are helpfully summarized in Gretton (2013). Gretton identifies five particular weaknesses that can be summarized as follows: input-output models focus attention on one set of economic dependencies - the reliance of a project on upstream sectors for inputs - but ignore other such dependencies.[9] The incorporation of upstream sectors into the analysis tends to expand the estimated impact of any given investment. In contrast, the interdependencies that are routinely ignored in input-output analyses would tend to limit or reduce the estimated impact of a project. It is for this reason that careful authors, like those in the NREL study, describe their estimate as gross effects of wind power, rather than net effects. Policy

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[6] The Meadow Lake wind farm has turbines located in neighboring Jasper county as well as in Benton and White Counties.
[7] NREL (2004) describes the JEDI model in detail. The model has been used to study the impact of the first 1000 MW of power in a series of individual U.S. states.
[8] Many states, including Indiana, host manufacturing firms that participate in these supply chains.
[9] See Gretton (2013) for a listing of the five dependencies not considered in the input-output framework.

decisionmakers should, of course, be interested primarily in the sector's net effect on their local economies, not the gross effects.

There are two additional weaknesses that apply to the input-output analysis of sub-national units, and these apply with greater force at the level of counties than at the level of states. First, the data describing input-output relationships in the economy are typically reported at the national level. Analysts typically use inference and assumptions to try to adjust this data to fit local conditions. Still, studies of smaller geographic areas must rely - to some degree - on data that is imputed or assumed rather than collected. Since the focus of this report is county-level outcomes, a much more significant problem applies leakages out of the county of interest are likely to be very significant. A significant amount of the additional income that county residents earn from the sector - payments the sector makes to labor for work done in the county, lease payments the sector makes to landowners - may leave the county before being spent if the workers and landowners are not residents of the county. A second complication for input-output analysis in this context is the relative absence of upstream sectors in the small rural counties that host wind-powered generation. The construction phase relies on a long and complex supply chain, but almost none of the manufacturing activities that support this supply chain are sited in the counties themselves. The operational phase relies on relatively few local inputs.

The analysis in NREL (2014) is conducted at the state level for Indiana. The authors provide separate estimates of indirect costs for the construction and operation phases of the wind projects. Separation of this kind is appropriate when possible because the construction phase is brief but high intensity, lasting one to two years but still accounting for most of the project's lifetime expenditures in the county. In the operation phase - which the NREL study judges to last twenty years - the project makes considerably smaller annual expenditures in the county but offers more durable support to the employment and incomes for which it is responsible.

The authors of NREL (2014) further divide their estimates into three kinds. *Direct effects* are the estimates of the industry's expenditures and employment. *Indirect effects* are those calculated by applying the multiplier associated with upstream purchases to the direct expenditures. The third attribution of benefits - which the report labels *induced impacts* - are calculations that consider downstream spending effects linked to the higher incomes earned by households who are paid by the sector. As with the indirect effects, these estimates focus on the extrapolations that attempt to quantify the recirculation of payments inside the local economy. The induced impact calculations are subject to many of the same critiques that Gretton (2013) outlines for calculations of indirect effects.

The direct effects are the most reliable estimates for making judgments about the sectors' local impacts. These are taken from surveys of industry participants and relate directly to the operation of the industry itself. The authors calculate that, during the two-year construction phase, Indiana's first 1000 MW of power was associated with the employment of 690 full-time equivalent (FTE) workers and $64.5 million of additional economic activity. In the operation phase, the authors attribute 96 FTE jobs to direct employment and $6.3 million in additional economic activity. They also estimate annual payments to landowners of $3.7 million per year and local property taxes of $6.3 million per year. Indiana now hosts approximately 2000 MW of installed capacity so that cumulative totals would be approximately twice as large as those reported in the NREL (2014).

The study's estimates of indirect impacts are that the first 1000 MW supported 2820 FTE jobs and generated $395 million of economic activity during the construction phase. In the operational phase, they attribute 94 FTE jobs to the industry and $24 million per year to local economies. The induced impacts were as follows: 900 FTE jobs and $108.7 million of economic activity during the construction phase; 73 FTE jobs and $8.79 million of economic activity during the operational phase.

III.b. Econometric studies of aggregate impact

For economic policy decision-making, input-output analyses have two main shortcomings; they calculate gross rather than net effects, and they do not acknowledge or report uncertainty around their estimates. These two shortcomings of input-output analyses are strengths for econometric studies. In this section, we review the findings of two such studies and apply the multipliers they derive to figures for installed generation capacity in Indiana counties. The studies use somewhat different statistical techniques, but arrive at very similar conclusions: 1) There is considerable uncertainty around the estimated impacts of wind energy generation on local incomes and employment; 2) the effects on average county incomes are nonetheless large enough that it is safe to conclude that wind energy generation raises average incomes in counties that allow it, and 3) both studies point to positive net effects on county employment, but these effects are not large enough to be judged to be statistically different than zero.

Brown *et al.* (2012) use data on Great Plains counties to study the impact of wind generation capacity added between 2000 and 2008. The authors measure a county's exposure to wind energy investments in terms of a variable that measures MW of capacity per person. Using an econometric method known as instrumental variables, which is well suited for this question, the authors estimate that, on average, the installation of an additional MW of capacity per person in a county raises income per capita there by just over $11,000.

One of the advantages of statistical approaches to studying such questions is that the methods acknowledge uncertainty and quantify it. The estimates produced in this study are subject to considerable statistical uncertainty but indicate a high degree of confidence that the effect of wind energy investments in a county on its average income is positive. The 95% confidence interval for the effect of an additional MW per person on per capita income is [$544, $21,755]. This means that the estimates imply 95 percent confidence that the true effect of an additional MW per person generates an increase in average income in the county that lies between $544 and $21,755.

In the same article, the authors use the same techniques to study employment and estimate that an increase in one MW of installed capacity per person raises per capita employment in the county by 0.48 jobs. The 95-percent confidence interval for this estimate is [-0.07, 1.03]. These estimates indicate that the effect of wind energy capacity on employment is, most likely, positive, but also that statistical uncertainty around this estimate does not allow us to conclude with high confidence that the net effect of the sector on employment is, in fact, positive.

A second econometric study investigates the effect of wind energy investments on economic outcomes in Texas counties during the years 2001-2011. De Silva *et al.* (2015) investigate statistical relationships between the 10-year change in installed wind power capacity and employment, the number of business establishments located in the county, average and median incomes, and local public finance variables that we discuss later. The authors use an ordinary least squares method and estimate that the effect of an additional MW of capacity per person raises average income in a county by $2,658. The 95 percent confidence interval for this estimate is [$636, $4680]. The estimates here are lower than in Brown *et al.* (2012), but also less variable. Still, once again, the estimates indicate high confidence that the true effect of wind power on the average income in a county is indeed positive. De Silva, *et al.* (2015) also study the effects of wind power on employment. Like Brown *et al*., they estimate a small positive effect on employment, but the statistical uncertainty around that estimate means that we are once again unable to conclude with high confidence that the industry's net effect on county employment is positive.

Although both studies indicated considerable variability in their estimates of the effects of new wind capacity on per capita income and employment, the two studies deliver similar results, even though they studied different samples of counties, over different periods, and used slightly different methods. Both studies found positive and statistically significant effects of added wind capacity on per capita income. The estimated effects of wind capacity on employment were large and positive, but subject to statistical uncertainty that limits our ability to attribute positive net effects on employment to the industry's presence.

Although it is important to acknowledge that the effects of wind power in Indiana on economic outcomes in Indiana might differ from what was observed in the Great Plains and Texas, these studies offer the most credible available way to infer the net impact of wind power on the economies of Indiana counties.[10] To guide the reader as to the most likely impact of wind power in Indiana, we apply the estimates from Brown *et al.* (2012) and De Silva *et al.* (2015) to data from Indiana counties on megawatts of installed capacity and population. For each county, we calculate the changes in per capita income and employment that are implied by each study, as well as the uncertainty around these estimates, by applying the estimates from those studies to the data from Indiana counties.

The results of this analysis are reported in Table 6. To illustrate how to interpret the results in this table, we discuss the results for Benton County, a low-population county with a large amount of installed wind capacity. The implied effects on other counties are reported in the table and are generally smaller. Applying Brown *et al.* (2012) estimates to Benton County's data on population and installed capacity generates an estimated increase in average incomes in Benton County of approximately $1270 per year. Because of statistical uncertainty, the $1270 figure is overly precise. The 95% confidence interval in Brown *et al.* (2012) implies that the true effect on Benton County incomes probably lies somewhere in the range between $62 per person and $2480 per person, per year. $1270 is the most probable estimate in that range. The implied effects of the De Silva *et al.* 2015) study indicate a range of between $72.5 per person and $533 per person per year, with a central estimate of $303.

Benton County's combination of a relatively low population with a large base of installed wind capacity means that these studies imply large effects on Benton County's employment and even larger confidence intervals; in both cases, the confidence interval contains zero. Brown *et al.*'s estimates suggest that the change in employment lies between -69 and 1016, with an implied central estimate for Benton County of 473 new jobs. De Silva *et al*.'s estimates indicate that the employment effects lie between -247 and 2564 jobs, with a central estimate of 1163.[11]

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[10] Statistical analyses like those in Brown, *et al.* and Silva, *et al.* require a large number of counties to have adopted wind in order to reach firm conclusions. Since Indiana has relatively few counties that have adopted wind it is not possible to do this kind of study solely in an Indiana setting.

[11] The central estimate of changes in employment in Benton County is implausible. Bureau of Labor Statistics Data indicates that employment in Benton County in 2019 was 2,283. The multiplier that is applied here relates to a county's MW/capita, and Benton County has unusually large ratio of installed capacity to population. This is one

Table 6. Wind power impacts on Indiana counties economics

County	Capacity installed (MW)	Population (2018)		Brown *et al.* (2012) estimates		De Silva *et al.* (2015) estimates	
				Per capita income ($)	Employment	Per capita income ($)	Employment
Benton	986	8,653	**Mean estimate**	1270	473	303	1163
			95% interval	[62, 2480]	[-69, 1016]	[72.5, 533]	[-247, 2564]
Jay	120	20,764	**Mean estimate**	64.5	58	15.4	142
			95% interval	[3.14, 126]	[-8.4, 124]	[3.7, 27]	[-30, 312]
Madison, Tipton	203	144,770	**Mean estimate**	15.63	97	3.73	240
			95% interval	[1, 31]	[-14, 210]	[0.9, 6.6]	[-51, 528]
Randolph	200	24,850	**Mean estimate**	90	96	21.4	236
			95% interval	[4.4, 175]	[-14, 206]	[5.12, 38]	[-50, 520]
White	801	24,133	**Mean estimate**	371	385	88.2	945
			95% interval	[18, 722]	[-56, 825]	[21, 155]	[-200, 2083]

Sources: AWEA Wind Project Mapping Portal, United States Census Bureau, Brown et al. (2012), Silva et al. (2015). Note: Capacity installed is the total capacity installed of all wind farms in a county. Changes in per capita income were calculated by multiplying the estimates of the effect of capacity installed per capita on income per capita by the ratio of installed capacity to population. Employment was calculated by multiplying the estimates of the effect of changes in per capita capacity installed on per capita employment and multiplying by the county's population. Madison and Tipton counties are aggregated for our calculations because their only installed turbines sit on the border between the two counties.

These estimates are indicative of the uncertainty surrounding the employment effects of wind energy generation. Although there are high paying maintenance jobs in the sector, the absolute number of these is small and can be swamped by other local developments in county economies,

illustration of the lack of precision in the available estimates of the effects of wind power generation on net employment. This lack of precision is also evident in the large confidence intervals surrounding the estimates.

even in small rural economies. The econometric results include net effects, including spillovers and externalities, on employment. Unfortunately, the variability of the measured effects across all the affected counties in the data is so large that it makes it difficult to establish with high levels of statistical confidence that the average net effect of the industry on local employment is positive.

Although it is clear that there is some direct employment by the sector in the counties - mainly in counties with large wind sectors such as Benton County - the statistical evidence to date does not point to the industry's presence is large enough to generate net gains in employment that are observed consistently across counties that accept wind turbines. In terms of aggregate effects, the evidence that the sectors' presence raises local incomes is much stronger than the evidence indicating it increases local employment.

IV. Impacts on the distribution of income

The relatively large and statistically significant effect of the industry on average incomes in the econometric studies obscures a question that is important for broader political acceptance of the industry in Indiana counties. Much of the measured increase in average income may be due to large payments to a small number of landowners and relatively high salaries paid to a relatively small number of workers, especially those that install and maintain the turbines. If the industry generates few spillovers to the rest of the economy, then the majority of the population may not see a significant increase in their own incomes when new generating capacity is installed. Measuring the effect of the sector on the local distribution of income is difficult, and there are not yet any available studies that address the question directly.[12] One of the primary sources of friction in the local political debates about the decision to allow utility-scale wind energy investments is likely to be the uneven distribution of the benefits. Survey evidence from Michigan indicates that residents feel that wind turbines create tensions within their communities because some landowners receive revenues from wind turbines, and the others do not (Mills, 2016).

Key challenges, for the industry and local policymakers, are to design policies that spread the economic benefits of the sector more widely and to communicate the ends and means of those policies more clearly. The most practical way to spread the economic benefits of the sector to the broader community is likely to be through payments to local governments. We review the evidence

[12] De Silva, *et al.* (2015) conduct the most comprehensive study of county level outcomes. They find statistically significant and positive effects on average incomes, while the effects on *median* incomes are not statistically significant. The point estimates for changes in the two variables are very similar though, so it is difficult to take this as conclusive evidence that the industry has a deleterious effect on the distribution of income.

on the industry's effects on public finances separately in a section below. Another approach to spreading the benefits is for the industry itself to widen the set of landowners who receive lease payments. In a news article, the University of Michigan researcher Sarah Mills reports seeing "an uptick in royalty payments that expand the pool of landowners who receive money from development — not just those with wind turbines on their property."[13] In other quite different contexts, revenues from resource extraction industries have financed direct payments to the citizenry, whether they be landowners or not.[14]

If the spillover effects of the industry are significant, so that the presence of a sector contributes to a general increase in local economic activity, one could see the benefits shared more broadly that way. This might be difficult to detect in a rigorous study, and we know of no studies that show, for example, reduced poverty rates or other such evidence that would be consistent with the industry generating broadly-shared increases in local incomes.

V. Impacts on local public finances

The wind energy profile section of this report provides evidence that the industry has directly improved local public finances of specific counties in Indiana.[15]

The econometric literature on the impact of wind energy on local public finances is small but nonetheless informative. The broad lesson seems to be that the presence of utility-scale wind energy generation can be a boon to local governments - local school districts, mainly - but that whether or not additional tax revenues translate into higher school expenditures depends on institutional features such as offset funding from the state. There is also reasonably good evidence that counties that allow installation of industry-scale turbines are able to reduce the local tax burden.

In their study of Texas counties, De Silva *et al.* find that wind turbines raise the tax base of counties in which they are located. They estimate that a 10 percent increase in wind capacity generates an approximate 4.4 percent increase in the size of the county's tax base, after controlling for the overall size of the tax base (because the tax base depends on wind capacity), the authors estimate

[13] See Balaskovitz (2017).
[14] The best known of these in an American context are the annual oil dividend payments made to Alaskans from the Alaska Permanent Fund Corporation.
[15] In 2019, White County collected $2.2 million of property taxes from the wind industry and received another $450,000 from an economic development agreement. Benton County received $3.6 million in property taxes from the industry in 2018.

that a 10 percent increase in wind capacity generates a 2 percent reduction in local property tax rates. School tax rates in Texas do not appear to have been affected by the presence of the arrival of wind generating capacity. It seems that reduced payments from the state offset some portion of increased school tax revenues that come through the larger tax base. In the end, the authors find no statistically significant effect of wind capacity on total per-student expenditures in the local schools, but they do find an increase in the portion of per-student spending that is financed through local taxes.

A somewhat cruder statistical analysis by Castleberry and Greene (2017) uses data from 108 school districts in Oklahoma from 1997 to 2015 to examine the effects of wind development on school funding.[16] In their analyses, the authors utilized t-tests for independent samples and Mann-Whitney U tests to evaluate changes in the distribution of growth rates across school districts that did and did not receive new installed wind capacity. The results show that districts with turbines installed before 2011 observe an average increase in local and county revenues of 59.8%, while the revenues of those without turbines only increase by 27.8%. The statistical tests reveal no statistical differences between districts with and without wind turbines for a variable measuring changes in the student/teacher ratio. Only several isolated districts with wind generating capacity saw a decrease in student-teacher ratio. Finally, the authors found that, on average, there is no statistical difference between districts with and without wind capacity concerning the percentage change in per-student expenditures. The authors argue that the main benefit of wind turbine installation for the affected school districts is that higher revenues from local sources leave them less exposed to sudden changes in funding from state and federal governments.

VI. Effects on the structure of local economies

Implicit in many views of the economic impact of wind turbines – both positive and negative opinions - are assumptions about one or another structural impact of the wind generation industry on other sectors in the local economy. It may be, for example, that the additional income the industry brings to the county increases the health of the local retail sector, which might otherwise be vulnerable in small rural counties. It may also be that well-paying jobs in the wind energy sector lure conscientious and hard-working local employees away from working in other establishments,

[16] Because these authors are studying school districts – not counties, as most studies do – they do not have a wide range of county level data that can be included as covariates in regression analysis. Instead of regression analysis, the authors do tests for differences in growth rates of variables across a sample of school districts that did and did not have turbines installed during the time of study.

a form of "crowding out." Input-output studies such as NREL (2014) imply that industry expenditures repeatedly circulate through the local economy, with industries that sell directly to the wind sector benefitting disproportionately from the arrival of wind turbines in the county.

Impacts on the structure of the economy are an understudied issue, perhaps because the hypothesized effects are weak. The De Silva *et al.* study of Texas counties is an exception to the rule. In this study, the authors use data on county business patterns, and ask whether the installation of new wind generation capacity affects the number of business establishments or the number of employees in the county - in the aggregate, and across 20 different sectors of the local economy. Their estimated effects on aggregate employment have been reviewed above: the estimated effect is positive, but not statistically different than zero. De Silva *et al.* find a similar result for the impact of wind capacity on the number of business establishments, an estimate that is positive, but not large enough to be distinguished, statistically, from zero.

When the authors turn to sector-level analysis, they find some statistically significant effects. They estimate a negative effect on the number of establishments in the agricultural sector and a positive effect on the number of establishments operating in the utility sector. These effects are statistically significant, with 90 percent confidence, but not with the conventional threshold of 95 percent confidence. The most substantial measured effects of wind capacity are in the mining sector - these effects are positive and statistically significant at the 95 percent level of confidence. Likely, the measured increase in establishments in the mining and utilities sectors is directly related to the appearance of the industry itself. The other 17 sectors saw no statistically significant change in the number of establishments due to growth in wind energy capacity.

The authors also investigate changes in employment at the sector-level. Sectoral employment is arguably a more interesting outcome of studying than the number of establishments because overall employment in a sector can increase without growth in the number of establishments (if the existing establishments simply hire more workers). The authors find a large, positive, and statistically significant estimate of the effect that new wind generation capacity installations have on local retail employment. The estimates suggest that each 100 MW of new capacity generates an additional 20 jobs in the retail sector. Employment in the waste management sector also increases due to the arrival of the wind energy generation, with the effects taking similar magnitudes to those estimated for retail employment. The other 18 sectors that De Silva *et al.* study did not experience a statistically significant change due to the presence of the wind sector. The estimated effects on these other sectors are both positive and negative, which helps to explain the absence of a statistically significant effect on aggregate employment.

De Silva *et al.* appear to be the only study that investigates these spillover effects econometrically, relating the experience of counties with installed wind generation capacity and comparing them statistically to otherwise similar counties without wind energy generation. The study evaluates the economic consequences of wind energy generation in Texas and relies on developments in the 31 Texas counties in which wind energy generation was installed. The results are nonetheless plausible, and therefore intriguing. The increase in average local incomes that appears to be associated with the arrival of the wind sector should help to support local retail activities. Increased incomes, along with the activities of the sector itself, may increase demand for waste management services. The location of large-scale wind energy generation might also crowd out some agricultural firms, as the authors estimate.[17]

The evidence of negative effects on the number of establishments engaged in agriculture may need some perspective. Farmers who are also landowners likely benefit from the additional income from lease payments paid to compensate for the use of their land. Since lease payment income is predictable and largely uncorrelated with developments in weather and commodity markets, it may be especially valuable as a source of farm income. Mills (2018b) surveys farmers in Michigan, asking respondents about their investments in buildings and equipment, and succession plans for their farm. She finds that farmers receiving lease payments invest more in their on-farm buildings and equipment, and are more likely to have succession plans for their farm. In this way, the sector may help to support the economic viability of farms that do receive lease payments, even if it also crowds out some farms or other agricultural business establishments.[18]

VII. Possible externalities created by wind farms

One of the most salient issues in local decision-making about the acceptance of utility-scale wind investments relates to the possibility that the turbines impose sizable externalities on residents of their local areas. Externalities are social costs or benefits that the industry brings to the county that

[17] In a footnote, the authors say that the estimated the effect of wind energy capacity on harvested acres and found a negative but statistically insignificant effect.
[18] Set-back requirements that local governments use to regulate the location of turbines make them easier to locate on the land of landowners with concentrated holdings. It may be that the estimated negative effect of wind capacity on agricultural establishments reflects the fact that counties with falling numbers of local farms are able to have more turbines sited because property ownership in those counties is becoming more concentrated (and thus less constrained by set-back requirements). It may also be that the prospect of new wind farms leads land ownership to become concentrated, in order to avoid having the set-back requirements constrain landowners' opportunities to receive lease payments.

are not fully incorporated into the industry's decision to install turbines in a given location. One of the inescapable facts of large-scale wind turbine installations is that they bring a significant change to the rural landscape. Some citizens see the turbines as disamenities, which is an example of a negative externality. Critical questions regarding negative externalities are: how significant is the harm; should there be compensation, and if so, to whom and how much? A considerable part of the academic literature on the wind turbine industry has asked whether proximity to new wind turbines reduces the value of nearby properties. Economic research has also indicated the presence of some positive externalities linked to the industry. In this section, we first provide a brief guide to the literature on changes in real estate values and then discuss recent research indicating positive externalities.

VII.a. Consumption externalities

There is considerable heterogeneity – across individuals and communities – in attitudes towards large-scale wind turbines.[19] Wind turbine projects across rural Indiana have faced opposition from local citizens. Often, this opposition has led to local regulations that effectively preclude investment, to moratoria, or even to outright bans on the development of new projects. One of the primary motivators of this opposition, in Indiana and elsewhere, is the view that the turbines are an important disamenity for residents.

A broad literature has attempted to quantify the disamenity value of nearby turbines. The most reliable studies on this topic are likely those that assess changes in house prices, comparing changes in the prices of houses with similar characteristics that differ in their level of exposure to the turbines. Purchases of houses are large expenditures, taken with considerable care, and therefore likely to represent carefully considered opinions about the implicit costs or benefits of living near the turbines. Evidence that the location of turbines near a property causes its value to fall, relative to similar houses that are less exposed to the turbines, would offer fairly convincing evidence that the turbines imposed a negative externality on those living near them.

The literature on this topic is large and growing, but still inconclusive. Vyn (2018) notes that the earliest studies on the topic had difficulty reaching firm conclusions because they lacked a sufficiently large number of real estate transactions to allow firm conclusions. Hoen *et al.* (2015) argue that a particular problem has been the absence of a sufficiently large number of real estate transactions located very near the new turbines. In earlier studies, inferences about the impact of turbines on nearby properties were made using estimates from data that mostly relied on

[19] See Vyn (2018) for a discussion.

transactions involving much more distant properties. Given the large setback distances and the placement of Indiana's turbines in quiet rural settings, it is likely that the relatively small number of retail transactions in close proximity to the turbines would pose an important problem for any study of the turbines' effects on Indiana's real estate prices.

Rather than review the literature extensively, we offer a brief review of three large-sample studies: Hoen, *et al.* (2015), Vyn (2018), and Jensen, *et al.* (2014). These studies are all fairly recent. Each offers a helpful review of the earlier literature on the topic, with different authors offering informed summaries of different issues in the literature.[20] Finally, the different focus of each study offers some helpful insights into the nature of the mechanisms at work.

The research by Hoen *et al.* (2015) was the first study of U.S. data that recognized that the earlier literature had been bedeviled by small sample sizes and set out to remedy it. The authors estimate an econometric model using transactions from 27 counties in nine different states – including Ohio, Illinois, Iowa, and Minnesota in the Industrial Midwest. The authors use data on more than 50,000 home sales, including 1198 sales within one mile of a turbine and 331 sales within ½ mile of a turbine. They divide the data into sales that occurred before the announcement of a project, after the project's announcement but before construction, and the period after construction. Despite a much larger sample than earlier studies, the authors still do not have enough evidence to conclude that either the announcement of pending construction or construction itself is sufficient to cause a statistically significant negative effect on house prices on properties with one mile (or even ½ mile) from the nearest turbine. The authors acknowledge that negative effects are still possible, even if they were too small to detect in their study. They argue that their lack of conclusive evidence for negative impacts of turbines on nearby property values, together with the available evidence on the effects of plausibly greater nuisances (road traffic, waste dumps, power lines) on property values suggests that the negative effects of turbines on nearby property values are unlikely to be large. They conclude that the effects of industrial-scale turbines on the value of property within one mile of a turbine are likely to be no larger than 3-4 percent of the value of the property, and probably smaller. It is also likely that these effects will diminish over time, as people with a smaller aversion to the turbines come to live in the properties nearest them.

Jensen *et al.* (2014) conduct a large-sample study of changes in the response of property values in Denmark to the construction of nearby wind turbines. The large number of turbines in Denmark, combined with its moderately high population density – even in rural areas – means that these authors can collect a relatively large number of rural real estate transactions in the neighborhood of new turbines. Although the situation in Denmark is quite different than that in Indiana, we

[20] Interested readers are encouraged to consult these studies for a more detailed review of this literature.

include the Jensen study in this review because it offers a thorough description of the sources of negative externalities that might be associated with living near a turbine, and a careful study of their effects. The authors use detailed data on the terrain, house sizes, and the location of turbines to determine if the turbines are visible from each house.[21] The authors also calculate the exposure of each property to noise from the turbine. Taking all this into account, the authors estimate that having a view of a turbine reduces the value of a property in Denmark by 3.15 percent, on average. A more distant view implies smaller impacts on property values, as might be expected. Variation in the sound level also affects property values. Sound levels of 40-50 decibels were associated with a 6.69 percent reduction in the value of a property. Since properties that are closer to turbines are more likely to be more exposed to the visual sight of the turbine and to higher sound levels, distance offers a useful proxy for the joint effects of the two disamenities. The authors estimate that houses that are 800 meters from a turbine (approximately ½ mile) see the value of their property fall by 10.2 percent. At 1600 meters, approximately 1 mile, the effect falls to 5.4 percent.

How should we understand the rather large estimates coming from Denmark, viewed against the statistically insignificant (and small) effects estimated for the United States? Denmark has much higher population densities in its rural areas. Given the scale of the wind generation industry in Denmark, and its considerable geographic spread, the Danish people may have less choice about whether or not to live near turbines. A study from Ontario, Canada offers intriguing evidence related to this hypothesis.

Vyn (2018) offers a helpful up-to-date review of the available economic literature on the external effects of wind turbines. He especially notes that individuals and communities differ markedly in their attitudes towards new turbines. He argues that Ontario offers a useful laboratory for understanding how local attitudes and community dynamics affect the magnitude of the external effects of turbines on property values. Vyn notes that Ontario - unlike Indiana and most U.S. states - gives the provincial government, not local communities, the authority to decide whether or not wind farms are sited in a given location. Some communities welcome the turbines, while others are strongly opposed. Many communities voiced formal opposition to their wind farms, passing a resolution that they are "unwilling hosts" of utility-scale wind energy generation. Since communities in Ontario that express opposition often have turbines located there anyway, Vyn can compare the effect of turbines on property prices in communities that oppose the turbines to the effect on prices in communities that do not express formal opposition.

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[21] Most other studies use distance from the turbine as a simple proxy for exposure to its potential disamenities. Jensen, *et al.* also report estimates using the distance proxy.

A large number of turbine locations in Ontario (together with somewhat higher population density than is common in Indiana's wind counties) mean that Vyn also has a relatively large sample (of almost 17,000 transactions). Like Hoen, *et al.*, Vyn studies separately the effect of turbines on sales that occurred after the announcement of a project but before construction and the effect on sales that occurred after construction. He also studies whether the density of nearby turbines matters (e.g., whether having several turbines within one mile of the property has a larger effect than having a single turbine within one mile).

The most interesting of Vyn's finding is that a community's attitude towards the turbine determines whether or not there is a statistically significant effect on real estate prices. Communities that express formal opposition to turbines – but then receive them anyway – see negative effects of turbines on property values. The size of these effects is between 5 and 10 percent of the value of the property and applies to properties within 4 km (about 2.5 miles) of the nearest turbines. Property values are affected both in the period between announcement and construction and in the period after construction. By contrast, in communities that do not express opposition to turbines, the effect of turbines on property prices tends to be positive, though not statistically significant. Vyn also studies the effect of turbine density on property values. In communities that are opposed to wind power, he finds that a larger number of turbines within a given radius of property cause a larger reduction in the property value.[22] In communities that have not expressed opposition to turbines, however, he finds no evidence of a relationship between turbine density and property values. In communities that accept wind power without formal opposition, turbine density does not appear to matter for property values.

Vyn's findings have at least two important implications for this study. First, they highlight the critical importance of understanding community attitudes towards wind power, as well as the community dynamics that lead some counties to oppose wind power while other communities welcome it. Second, the research helps explain why authors such as Hoen *et al.* find little or no impact of wind turbines on property values in the United States. Most areas of the United States – most notably counties of Indiana – have substantial influence over whether turbines are situated in them. Since the available data on real estate transactions near turbines in the United States would be dominated by real estate transactions in communities that chose to accept wind power, we should expect little or no impact on property values in the U.S. sample.

[22] He reports separate estimates indicating that the first turbine is responsible for about ½ of the total effect, the second turbine about ¼, with higher levels of turbine density offering rather smaller negative effects on house prices.

VII. b. External effects on crop yields

The literature on the effects of turbines on real estate prices investigates the possibility that turbines impose a negative externality on their neighbors. Recent studies have also found evidence of a positive externality. Wind turbines have been found to have small impacts on the weather in their immediate vicinity. Agronomic studies investigating the effects of these small changes in the "micro-climate" have found evidence that these effects of the turbines can have impacts on crop yields (Rajewski et al. 2013; Armstrong et al., 2014). To understand the direction and magnitude of those impacts, Kaffine (2019) estimates an econometric model relating changes in installed wind capacity to changes in station-level meteorological data. The second part of his econometric model links changes in meteorological data to changes in county-level data on crop yields. The results reveal that a 100MW wind farm increases corn yields in the same county by around 0.7% to 1.2%, an effect that is highly statistically significant. Wind farms also increase yields for soy and hay, with a magnitude of about 1% for soy and 1% to 3% for hay per 100MW capacity. The economic value of these effects is approximately $5 of local benefit for each Megawatt hour of generation.[23] The total economic benefit of the increase in yields generated by the sector's presence amounts to roughly $388 million of external benefits to farmers in U.S. counties where wind power capacity is installed.

The author conducts several robustness checks. He rules out the possibility that the productivity gain comes through new investments financed by new revenues from lease payments. He finds more substantial effects for taller turbines, and evidence that the benefits accrue primarily downwind from the turbines. All of these estimates are consistent with the agronomic understanding of how wind power affects crop yields.[24]

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[23] A Megawatt hour represents the provision of one MW of electricity for an hour of time.

[24] See Kaffine (2019) for details. The primary mechanisms are that the turbines reduce local wind speeds and generating mixing of the air, affecting crop-level temperatures, CO_2 and moisture levels. Agronomic understanding of these mechanisms indicate that they may operate up to 10km downwind from the turbines.

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